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(54) **Portable colorimeter and method for characterization of a colored surface**

Tragbares Kolorimeter und Verfahren zur Kennzeichnung einer farbigen Oberfläche

Colorimètre portable et méthode pour la caractérisation d'une surface colorée

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Description

This invention is directed to a portable colorimeter and a method for the characterization of a colored surface and in particular a color surface containing metallic or pearlescent particles.

In the manufacture of pigmented finishes one rarely, if ever, achieves a satisfactory color match versus a color standard without an adjustment process known as shading. Shading usually involves a relatively minor but critical manipulation of the formula pigment composition, correcting for the cumulative effects of manufacturing variables on pigment dispersions.

Traditionally, the shading process has been carried out by highly skilled and trained personnel who require extensive on-the-job experience to achieve proficiency in their craft. Since visual shading at best is an art, effective administration of the process was difficult.

In more recent years, such visual shading has been supplemented by the use of apparatuses for instrumentally characterizing a paint or pigment composition. Colorimeters and spectrophotometers are well-known in the art and are used to measure certain optical properties of various paint films which have been coated over test panels. A typical spectrophotometer provides for the measurement of the amount of light reflected at varying light wavelength in the visible spectrum by a painted panel that is held at a given angle relative to the direction of an incident source of light. The reflectance factor of the paint enables paint chemists to calculate color values by which to characterize various paint colors. For a paint containing no light-reflecting flakes or platelets (i.e., non-metallic paints), the reflectance factor will not vary with the angle of the panel relative to the direction of incident light except at the gloss (specular) angle. Consequently, a single spectrophotometric reading at any specified angle will produce a reflectance value by which to accurately characterize the paint.

However, the paint industry often utilizes light-reflecting flakes in paints (i.e., metallic paints) to obtain pleasing aesthetic effects. Paints containing light-reflecting flakes of such materials as aluminum, bronze, coated mica and the like are characterized by a "two-tone" or "flip-flop" effect whereby the apparent color of the paint changes at different viewing angles. This effect is due to the orientation of the flakes in the paint film. Since the color of such metallic paints will apparently vary as a function of the angle of illumination and viewing, a single spectrophotometric reading is inadequate to accurately characterize the paint. Although measurement studies have shown that visual color differences existing between two metallic paints were detectable at an infinite number of angles, it is obvious that practical reasons preclude the collection of reflectance factors for an infinite number of viewing angles. However, previous studies have also indicated that measurement of the optical properties of a metallic paint at only two or three specified angles can provide useful characterization. See, for example, U.S. Patent 3,690,771, issued September 12, 1972 to Armstrong, Jr., et al and U.S. Patent 4,479,718, issued October 30, 1984 to Alman, the disclosures of which are incorporated herein by reference.

Instruments have also been devised wherein measurements are taken at a fixed angle by varying the angles of illumination. See, for example, EP-A-0079517. Various other devices and methods are disclosed in US-A-3,389,265; 3,885,878; 3,916,168; 3,999,864; 4,449,821; 4,669,880; 4,711,580.

However, there is a need in the automobile paint industry for a colorimeter which is portable, compact and capable of measuring the color of automobile panels and the like, and especially metallic or pearlescent finishes.

As is known from EP-A-0079517, the invention provides a colorimeter comprising an irradiation means which comprises a plurality of light sources for sequentially illuminating a colour film sample from a plurality of corresponding illumination angles, a detector capable of detecting the light reflected from the sample at a detection angle different from any said illuminating angles, the detector including an analyser to analyse the light, a display to display the results of an analysis and control means to control the irradiation means, the detector, the analyser and the display. In contrast to EP-A-0079517 and in accordance with the invention there three light sources only which are disposed on a common plane normal to the sample surface and lie on an arc with its centre on the sample surface during use, the light sources being further disposed to illuminate the sample from three corresponding illumination angles having values of about -35° to -20°, -10° to +10° and 20° to 75°, as measured from the sample normal, an active feedback circuit is provided to maintain a fixed color temperature for the light sources in operation, the detector is disposed to receive reflected light in the same plane as the light sources and the light sources, the detector, the control means, the analyser, the active feedback circuit and the display are all integrated in a single housing whereby the colorimeter is portable in its entirety and can be sued in different locations to analyse the sample in situ.

In accordance with the another aspect of the present invention there is also provided a method of analysing the color of a color sample comprising the steps of:

(a) installing a portable colorimeter in a location in situ of the color film sample the colorimeter comprising irradiation means comprising three light sources only, which are disposed on a common plane normal to the sample surface and lie on an arc with its centre on the sample surface, an active feed back circuit for maintaining a fixed color temperature for the light sources, a detector for receiving reflected light in the same plane as the light source an

analyser for analysing the detected light, a display for displaying the results of the analysis and control means;

the light sources, the detector, the analyser the active feedback circuit the display and the control means all being integrated in a single housing;

(b) using the control means to control the detector, the analyser the display as well as the operation of the irradiation means and the feedback circuit to cause the light sources to illuminate the color film sample in a sequential fashion at a plurality of illumination angles corresponding to said light sources which are respectively about -35° to -20°, -10° to 10° and 20° to 75°, as measured from the sample normal;

(c) detecting sequentially the light reflected by the sample from each of said slight sources with the detector which is set at a detection angle different to any of said illumination angles;

(d) analysing the detected light with the analyser and

(e) displaying the results of the analysis with said display

The tristimulus values of the sample can be determined from the data produced by the analytical method and the colorimeter as defined above.

In accordance with another aspect of the invention the weighting coefficients for the tristimulus function curves x, y and z are determined by correcting the tristimulus function curves representing data sensitive to the human eye to multiplying the data by the spectral power distribution curve of the illuminant; determining the spectral response curve of the detector elements represented as a series of generally triangular pass band; and fitting the illuminant corrected tristimulus function curves with a multiple linear combination of the generally triangular pass bands representing the spectral response curve.

An embodiment of the invention will now be described with reference to the following description and the accompanying drawings.

In the drawings:

Figure 1 is a schematic illustration of a portable colorimeter constructed in accordance with the present invention;
Figure 2 is a schematic for the control circuitry of the colorimeter;
Figure 3 is a perspective view of the colorimeter showing the necessary parts only;
Figure 4 is a representation of the operator key pad;
Figure 5 is an illustration of the measuring surface of the colorimeter;
FIG 6 is a view taken along line 6-6 of FIG. 5;
FIG 7 is an illustration of the measuring surface resting on the color sample;
FIG 8 shows the tristimulus function curves representing the sensitivity data of the human eye;
FIG 9 is the spectral power distribution curve for the illuminant;
FIG 10 shows the illuminant corrected tristimulus function curves;
FIG 11 shows the spectral response curves of the detector elements as represented by a series of triangular pass bands;
FIG 12 shows the weighted detector response function curves;
FIG 13 is a comparison of the invention with the prior art.

In optically characterizing surfaces containing metallic particles, such as metallic paints and films, it was recognized that directional reflectance had to be considered. Metallic paints contain light-reflecting flakes or platelets of such material as aluminum, bronze, coated mica and the like. These flakes or platelets function much like little mirrors, reflecting light directionally rather than in a diffuse manner. The directional reflectance characteristic of a metallic paint film results in a phenomenon known as goniochromatism, which is defined as the variation in color of a paint film as a function of the directions of illumination and viewing. This phenomenon is also sometimes described as "two-tone", "flop" "flip-flop", "flash", "side-tone", etc. In sum, the color of a metallic paint will appear different at different viewing and/or illumination angles.

To account for this directional or angular reflectance, i.e., goniochromatism, spectrophotometrically determined reflectance factors must be taken multiangularly. The reflectance factor of a paint film is the ratio of the light flux reflected from the film sample to the light flux reflected from a perfect reflecting diffuser when the sample and perfect diffuser are identically irradiated. A perfect white reflector has a value of 1. A perfect black nonreflector has a value of 0.

The reflectance factors are used to calculate color descriptor values used to specify color and color difference. The tristimulus values (X, Y, Z) of a color are calculated by combining the reflectance factor data (R) with data on the sensitivity of the human eye ($\bar{x}$, $\bar{y}$, $\bar{z}$) and the irradiance of a light source (E) all as functions of wavelength (λ) in the visible spectrum. The defining equations for tristimulus values are:

$$X = \int_{360}^{830} R(\lambda)\, E(\lambda)\, \bar{x}(\lambda)\, d\lambda$$

$$Y = \int_{360}^{830} R(\lambda)\, E(\lambda)\, \bar{y}(\lambda)\, d\lambda$$

$$Z = \int_{360}^{830} R(\lambda)\, E(\lambda)\, \bar{z}(\lambda)\, d\lambda$$

The tristimulus values can be used to calculate color descriptors which relate to visual perception of color and color difference. One of many sets of descriptors which can be used is the CIELAB perceptual color scale recommended by the International Commission on Illumination ("Recommendations on Uniform Color Spaces, Color Difference Equations, Psychometric Color Terms", Supplement No. 2 To CIE Publication No. 15 (E1.3.1) 1971/CT(1.3) 1978. Bureau Central De La CIE, 52 Boulevard Malesherbes 75008, Paris, France).

Transformations of the tristimulus values can be used to calculate perceptual color values describing lightness (L*), redness/greenness (a*), yellowness/blueness (b*), saturation (C) or hue (h). A color can be completely described by a set of L, a, b or L, C, h values. The following equations which have been specified by the International Committee on Illumination relate the tristimulus values to L*, a* and b*

$$L^*=116(Y/Yo)^{1/3}-16$$

$$a^*=500[(X/Xo)^{1/3}-(Y/Yo)^{1/3}]$$

$$b^*=200[(Y/Yo)^{1/3}-(Z/Zo)^{1/3}]$$

where

Xo, Yo and Zo are the tristimulus values of the perfect white for a given illuminant;
X, Y and Z are the tristimulus values for the color.

The saturation (C) and hue (h) descriptors are related to the a* and b* values as follows:

$$C=(a^{*2} + b^{*2})^{1/2}$$

$$h=\tan^{-1}(b^*/a^*)$$

Often it is necessary to compare a color, such as a sample batch of paint, to a standard color and determine the difference and then adjust the sample with appropriate additives to bring the sample within tolerance values of the standard. The difference in color between a color standard and a batch sample is described as follows:

$$\Delta L^*=L^*(batch)-L^*(standard)$$

$$\Delta a^*=a^*(batch)-a^*(standard)$$

$$\Delta b^*=b^*(batch)-b^*(standard)$$

The resultant values agree with the visual assessments of differences in lightness (ΔL^*), redness/greenness (Δa^*) and yellowness/blueness (Δb^*).

Further discussion will employ the tristimulus values (X, Y, Z) and perceptual color values (L^*, a^*, b^*, C, h) to quantify the influence of changing conditions of illumination and viewing on measurement of goniochromatic color. The specific color descriptors employed are only one of many possible choices of transformations of tristimulus values which could be employed in this task.

The method used in the portable three angle colorimeter of this invention to calculate color constants X, Y, Z of a sample is different from that used in conventional filter colorimeters or spectrophotometers.

Filter colorimeters utilize optical filters whose transmission spectra have been tailored such that the product of the spectral power distribution curve of the light source, the filter transmittance curve and the detector spectral response curve closely approximate the tristimulus response functions ($\bar{x}$, $\bar{y}$, $\bar{z}$ response of the human eye) for a given illuminant. The signal from each of three detectors (red, yellow-green, and blue) relative to a white standard gives a direct measurement of the color coordinates of a sample. To measure color under a different illuminant would require a different set of filters. (See, for example, U.S. Patent 4,711,581 to Venable).

Conventional spectrophotometers measure the reflectance of the sample at a series of evenly spaced non-overlapping intervals (typically 10 nm) across the visible portion of the optical spectrum. These reflectance values are then multiplied point by point by the tristimulus response functions ($\bar{x}$, $\bar{y}$, $\bar{z}$) corrected for the illuminant and/or observer of choice. Properly normalized the sum of these products yield the color coordinates for the sample. In typical spectrophotometers anywhere from 16 to 31 detectors are employed for the point by point measurement of the visible spectrum. Description of such conventional measurement can be found in Publication CIE No. 15 (E-1.3.1) 1971, COLORIMETRY.

In the method employed by the portable colorimeter described below, however, the sample reflectance spectrum is determined, preferably by using only twelve detector elements. The spectral sensitivity or response of each of the twelve detector elements is described by a generally triangular shape pass band which is a representation of the shape of the intensity envelope with respect to wavelength location. The illuminant corrected tristimulus function curve is then fit by a multiple linear combination of these triangular shape pass bands which when properly normalized yields color constants, i.e., tristimulus values X, Y, Z.

Relying on a conventional principle that three properly selected measurement angles are an optimized selection to give maximum information on metallic color for minimum measurement effort, a portable instrument has been constructed. However, in order to minimize space requirements, the portable three angle colorimeter employs a reverse geometry. The conventional method used multiangular spectrophotometric measurements taken at three specified angles, preferably 15°, 45°, and 110° as measured from the specular angle, with a single light source having an illumination angle of 45° relative to the metallic paint sample being measured (which is the same as saying the light reflected is detected at -30°, O°, and 65° as measured from the sample normal).

However, in the portable colorimeter of this invention, multiple light sources sequentially illuminate the sample at angles of about -35° to -20°, -10° to +10° and 20° to 75°, preferably from -30°, O°, and 65° as measured from the sample normal, and light reflected from the sample is detected at a detection angle from about 35°-55°, preferably at 45°, as measured from the sample normal.

In addition, the portable instrument of this invention employs a different method for determining the tristimulus values X, Y, Z, of a paint sample by using low resolution spectral data obtained from a silicon photo diode array detector, preferably comprising only twelve elements for detection across the entire visible spectrum (380 nm - 700 nm). By this method, the illuminant corrected tristimulus function curve is fit with a multiple linear combination of the triangular pass bands for each of the twelve elements.

As schmatically shown in Figure 1, the portable colorimeter 10 of this invention employs three sources of illumination, lamps 11a, 11b, and 11c. The output of these lamps is collimated by each achromatic source lens 12a, 12b, and 12c mounted at its focal length form the lamp filament. Each lamp may be a 20 watt quartz halogen lamp, such as the lamp manufactured by Gilway Technical Lamp, Model Number L7404. In order for the measurement technique employed in this device to work properly it is necessary that the lamps operate at a fixed color temperature as will be discussed below. The lenses employed may be Model Number OILAU004-006, manufactured by Melles Griot.

The collection optics may include a single achromatic collection lens 13 (Melles Griot OILAU006-006) mounted at

twice its focal length from the sample surface 14. A monochromator 19, comprising a diffraction grating 17 and a silicon diode array detector 18 is mounted opposite to the sample side of lens 13. Entrance slit 15 to monochromator 19 is mounted at a distance of one focal length from lens 13. This arrangement permits only light 16 which is very nearly collimated to pass through entrance slit 15 permitting only light scattered at or about 45° from the sample normal to enter the monochromator 19.

After passing through entrance slit 15, light 16 diverges until it hits the diffraction grating 17 where it is dispersed and refocused onto a silicon diode array detector 18 with twelve detecting elements 21. The diffraction grating 17 may be Model Number #523-00-460 as manufactured by Instruments SA. The array detector 18 may be Model Number LD20-5, as manufactured by Centronics. Preferably, the dimensions of the entrance slit are 0.9mm X 4.0mm.

The visible spectrum of light is 16 is dispersed and refocused across array detector 18. As schematically shown in Figure 2, each of the elements 21 of the photodiode array detector 18 has an associated amplifier 24 which converts the diode current to a voltage signal. The twelve signals are then multiplexed by multiplexer 27 and digitized by an analog to digital converter 28. The amplifier may be Model No. OPA2111 as manufactured by Burr-Brown. The multiplexer 27 may be Model Number AD7506KN as Manufactured by Analog Devices. The analog to digital converter may be Model Number ADC71JG as manufactured by Burr-Brown.

All of the functions are controlled by microcomputer 29, which may be an INTEL 8052 based computer with auxilliary I/O and memory card. The measurement data as will be described below derived from the portable instrument is displayed on an LCD display 30.

As can be seen by Figure 1, in portable colorimeter 10, the sample is sequentially illuminated, preferably from -30°, O°, and 65° as measured from the sample normal. Light reflected from the sample is detected, preferably at 45° as measured from the sample normal. It should be noted that the illumination and detection angles may be varied and the specific angles provided herein are merely optimum values.

As mentioned above, for proper operation of the colorimeter, the illumination source lamps 11a, 11b, and 11c operate at a fixed color temperature. Since the lamps are turned on only for a few seconds each per measurement, time is insufficient to allow the lamps to "warm up" to equilibrium in order to achieve consistent color-temperature. Thus the lamps, as schematically shown in Figure 2, are controlled by an active feedback circuit. Each source lamp 11a, 11b, and 11c is monitored by two photodiodes 22. A blue filter 23a is placed in front of one photodiode and a red filter 23b is placed in front of the other. Each of these diodes produces a voltage signal which is proportional to the lamp emission in the blue and red regions of the spectrum, respectively. The control circuit as schematically designated by block 25, adjusts the lamp current to maintain a fixed ratio between the output voltages of the two diodes, thus maintaining a fixed color temperature.

Figure 3 shows a plan view of the interior of portable colorimeter 10, illustrating only the parts necessary for an understanding of the invention. Schematically shown is the layout of the illumination sources as represented by illumination lenses 12a, 12b, and 12c; collection lens 13; lamp control circuit 25; card 38 which comprises multiplexer 27 and analog to digital converter 28; detector card 39 which comprises elements of photodiode array 21 and amplifier 24; computer control and analysis means 29; diffraction grating 17; and LCD display 30. The instrument may be powered by a remote battery pack 31 which may be shoulder mounted by an operator. Preferably, the instrument is of the approximate size 9cm x 20cm x 25cm (3 1/2" x 8" x 10") approximate weight of 3kg (7 lbs), and has a flat measuring surface of approximately 5cm (two inches).

An interface plate 33 mounts over the lenses 12a, 12b, 12c, and 13, and is affixed to mounting block 32 (Figure 5). Referring to Fig. 7, four magnetic feet 34 protrude through interface plate 33. Each foot 34 is a rare earth magnet which is covered with neoprene sheeting 35 of approximately 0.15 cm (1/16") thickness. The feet may be circular disc magnets of Sm/Co of approximately 1.3 cm (1/2") diameter and 0.95 cm (3/8") thickness, such as those manufactured by Crucible Magnetics. The feet 34 provide registration and resistance to slippage to a curved surface of an automobile panel to be measured, and the neoprene sheeting 35 provides protection to the car finish against, for example, surface scratching. In the center of the interface plate 33 is a donut shaped flexible magnet 36 which provides a light tight seal around measurement port 37. The spacing of the magnetic feet 34 and the distance that feet 34 protude define the minimum radius of curvature of the surface which can be measured, approximately 60 cm (24 inches). operator key pad is shown in Fig. 4.

The instrument is provided with an internal temperature monitor (not shown) located near the detector elements 21. Because of the instrument's portability, the temperature of the environment under which the instrument will be expected to operate may vary widely. To insure uniformity of results, temperature parameter limits are determined and preprogramed into the instrumentation. When such limits are exceeded, the operator is alerted and forced to recalibrate the instrumentation. The temperature sensing chip may be an Integrated Circuit Temperature Transducer AD592.

Three factors are essential for the production, perception and measurement of color: The source of light, the illuminated object, and the detector. Each of these three is described, by an appropriate response curve plotted against wavelength: the light source, by its spectral power distribution curve; the object, by its spectral reflectance or transmittance curve; and the detector, by its spectral response curve. The combination of these curves provides the stimulus,

or signal, which is represented as the numerical descriptors of color X, Y, Z - the tristimulus values. Thus the tristimulus values (X, Y, Z) of a color are calculated by combining the reflectance factor data (R) with data on the sensitivity of the human eye ($\bar{x}$, $\bar{y}$, $\bar{z}$) and the irradiance of a light source (E) all as functions of wavelength (λ) in the visible spectrum, as described above.

Figure 8 shows the tristimulus response functions curves $\bar{x}$, $\bar{y}$, $\bar{z}$ as cited in "Principles of Color Technology", page 44, 2nd Edition, Billmeyer and Saltzman, John Wiley & Sons (1981).

Figure 9 shows the spectral power distribution curve for the illuminant used. In the present embodiment two different standard illuminants are used. Figure 9 shows the spectral power distribution for CIE Source D65 which is a representation of average natural daylight over the visible spectrum having a correlated color temperature of 6500°K. The other illuminant source is CIE Source A which is a tungsten-filament lamp operating at a color temperature of 2854°K. For most applications of the portable colorimeter, the taking of measurements using these two variant illuminants at the three stated angles should suffice. However, it is well within the scope of this invention to employ other standard illuminants for taking measurements. The values for the spectral power distribution curve shown in Figure 5, are cited in "Principles of Color Technology", pp. 36-37, 2nd Edition, Billmeyer and Saltzman, John Wiley & Sons (1981).

By multiplying the tristimulus response curves (Fig 8) by the spectral curve for the illuminant (Fig 9) corrected response curves as shown in Figure 10, are produced.

Figure 11 shows the spectral response curves for the detector elements. The diagram represents data from photodiode detector array 18 which may be seen as a series of triangular pass bands 71 whose vertex is associated with wavelength 72. The spectral sensitivity of each of the twelve detector elements 21 is represented by triangular pass band 71 whose base width is equal to the portion of the spectrum subtended by two detector elements, i.e., 56-60 nm. Each of the corrected response curves of Figure 10 is fit with a multiple linear combination of detector response triangles from Figure 11. The multiple linear combination used is the same as that cited in "Applied Regression Analysis", page 178, Draper and Smith, John Wiley & Sons, Inc., NY (1966).

Figure 12 shows the result of this fit for the $\bar{x}$ tristimulus function of Figure 8, where each of the triangular pass bands has been weighted by the coefficients derived from the fit. A set of weighting coefficients for each tristimulus function curve and for each illuminant used may be derived. Thus, in the instrument of this invention three sets of weighting coefficients, one for each tristimulus function for illuminant A are derived and three sets of weighting coefficients for illuminant D65 are derived.

In the portable colorimeter 10, color coordinants are calculated in the following manner. The instrument is first zeroed by measuring a black glass tile (not shown). These values are subtracted from any future measurement. Then, the reflectance spectrum of a white calibration tile (not shown) is measured, and a series of gain coefficients is calculated to adjust numerically the response of each detector element 21 to be equal to the reflectance of the calibration tile at the appropriate wavelength. Any subsequent detector readings are multiplied by these gain coefficients.

To measure a sample panel, the colorimeter is first secured on the panel by magnetic feet 34, and lamps 11a, 11b and 11c sequentially illuminate the sample surface at -30°, O°, and 65° as measured from the sample normal. The light reflected from the panel is collected by lens 13 at 45° as measured from the sample normal, and is collimated to pass through entrance slit 15 to enter monochromator 19 (Fig. 1) Once in the monochromator, the collected light is detected by array detector 18 and ultimately converted to a voltage signal. The measurements taken are processed by microcomputer 29 and displayed on LCD display 30. The detector response for each of the twelve elements 21 is first multiplied by the appropriate gain coefficient and then by the appropriate weighting coefficient for the particular tristimulus value being calculated. The sum of these products is then scaled to correct for the X_o, Y_o, Z_o perfect white under the specific illumination conditions employed. These tristimulus values can then be converted into the desired coordinant system, for example, L*, a*, and b* or L, C, and h.

Figure 13 shows a comparison of tristimulus values X, Y, Z derived by the system of this invention versus the values obtained by a conventional laboratory spectrophotometric system.

The graph shows X, Y, Z color coordinants obtained for a set of twelve standard ceramic tiles, specifically Ceramic Colour Standards-Series II, as supplied by the British Ceramic Research Associated Ltd. For each tile, X, Y, Z, coordinants are obtained using first, the-portable instrument of this invention and second, a conventional system. The values for the portable colorimeter of the invention are plotted along Y axis and the values for the prior art instrument are plotted along X axis. Linear least squares fitting of the X, Y, Z data show a slope of approximately 1 and low scatter about the line. The graph illustrates comparable performance of the two instruments.

The colorimeter of this invention can be used to characterize not only metallic paint films but any surface containing metallic particles, such as plastic containing reflective metallic flakes and also can be used on solid colors, i.e., colors not containing metallic particles. The method is particularly useful in shading paint wherein the L*, a* and b* values are determined for a standard. Then a batch of paint is manufactured according to a given formula; a painted panel of the batch is made and the L*, a* and b* values are determined. Often the batch of paint, even if carefully made, does not match the standard because of variations in pigments and color drift of pigment dispersions. The ΔL*, Δa* and Δb* values of the batch are calculated and if outside of an acceptable tolerance value, calculations are made for the addition

of pigments in the form of mill bases and the mill bases added to the batch and a second panel prepared and values are measured as above. The process is repeated until there is an acceptance color match between the standard and the batch of paint.

While this invention has been described as having a preferred design, it will be understood that it is capable of further modification. This application, is therefore intended to cover any variations, uses or adaptations of the invention following the general principles thereof and including such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains, and as may be applied to the essential features hereinbefore set forth and fall within the scope of this invention or the limits of the claims appended hereto.

Claims

1. A colorimeter (10) comprising an irradiation means (12) which comprises a plurality of light sources (11a, 11b, 11c) for sequentially illuminating a color film sample (14) from a plurality of corresponding illumination angles, a detector (17,18,39) capable of detecting the light reflected (16) from the sample (14) at a detection angle different from any of said illumination angles, an analyser (38) to analyse the detected light, a display (30) to display the results of an analysis and control means (29) to control the irradiation means (12), the detector (17,18,39) the analyser (38) and the display (30); characterised in that there are three light sources (11a, 11b, 11c) only which are disposed on a common plane normal to the sample (14) surface and lie on an arc with its centre on the sample (14) surface during use, the light sources (11a, 11b, 11c) being further disposed to illuminate the sample from three corresponding illumination angles having values of about -35° to -20°, -10° to +10° and 20° to 75°, as measured from the sample normal, an active feedback circuit (22,25) is provided to maintain a fixed color temperature for the light sources (11a, 11b, 11c) in operation, the detector (17,18,39) is disposed to receive reflected light in the same plane as the light sources (11a, 11b, 11c) and the light sources (11a, 11b, 11c), the detector (17,18,39), the control means (29), the analyser (38), the active feedback circuit (22,25) and the display (30) are all integrated in a single housing whereby the colorimeter is portable in its entirety and can be used in different locations to analyse the sample (14) in situ.

2. The colorimeter (10) of claim 1, wherein the three light sources (11a, 11b, 11c) are disposed to illuminate the sample from three corresponding illumination angles having values of about -30°, 0°, and 65°, as measured from the sample normal.

3. The colorimeter (10) of claim 1 or 2, wherein said detection angle has a value of about 35° to 55°, and preferably about 45° as measured form the sample normal.

4. The colorimeter (10) of any one of claims 1 to 3, wherein said detector (17,18,39) includes an achromatic collection lens (13) mounted at a distance of about twice its focal length from the sample and a monochromator (19) comprising a diffraction grating (17) and an array of diode detectors (18) and wherein said monochromator (19) is mounted opposite to the sample side of said lens (13).

5. The colorimeter (10) of claim 4, wherein an entrance slit (15) to said monochromator (19) is mounted at a distance of about one focal length from said lens (13).

6. The colorimeter (16) of claim 4 or 5, wherein said array of diode detectors (18) includes ten to sixteen detector elements (21).

7. The colorimeter (10) of any one of claims 1 to 6, wherein said irradiation means (12) also comprises three lenses (12a, 12b, 12c) corresponding to said three light sources (11a, 11b, 11c), each of said lenses (12a, 12b, 12c) being mounted at a distance of about one focal length from a filament of corresponding light source (11a, 11b, 11c).

8. The colorimeter (10) of any one of claims 1 to 7 and further comprising:

   an interface plate (33) mounted over said irradiation means (12) and said detector (39,18);
   said interface plate (33) including a center port for allowing the light to pass therethrough; and
   means for releasable securing the colorimeter (10) on the sample (14).

9. The colorimeter of claim 8, wherein:
   said securing means comprises a plurality of magnetic feet (34) positioned around said centre port and

protruding through said interface plate (33).

10. The colorimeter of claim 9, and further comprising:

a generally donut-shaped flexible magnet (36) positioned concentrically with said center port for providing alight tight seal thereabouts; and
a resilient sheet (35) disposed between said interface plate and said flexible magnet (36) for protecting the sample surface (14).

11. The colorimeter of claim 8,9 or 10, wherein
said irradiation means (12) and said detector (39,18) are positioned in a semi-circle around said center port.

12. A method of analysing the color of a color film sample (14) comprising the steps of:

(a) installing a portable colorimeter (10) in a location in situ of the color film sample (14), the colorimeter comprising irradiation means comprising three light sources (11a, 11b, 11c) only, which are disposed on a common plane normal to the sample (14) surface and lie on an arc with its centre on the sample (14) surface, an active feed back circuit (22,25) for maintaining a fixed color temperature for the light sources, a detector (17,18,39) for receiving reflected light in the same plane as the light sources (11a, 11b, 11c), an analyser (38) for analysing the detected light, a display (30) for displaying the results of the analysis and control means (29);
the light sources (11a, 11b, 11c), the detector (17,18,39), the analyser (38) the active feedback circuit (22,25) the display (30) and the control means (29) all being integrated in a single housing;
(b) using the control means (29) to control the detector (17,18,39), the analyser (38), the display (30) as well as the operation of the irradiation means and the feedback circuit (22,25) to cause the light sources (11a, 11b, 11c) to illuminate the color film sample (14) in a sequential fashion at a plurality of illumination angles corresponding to said light sources (11a, 11b, 11c) which are respectively about -35° to -20°, -10° to 10° and 20° to 75°, as measured from the sample normal;
(c) detecting sequentially the light reflected (16) by the sample (14) from each of said light sources (11a, 11b, 11c) with the detector (17,18,39) which is set at a detection angle different to any of said illumination angles;
(d) analysing the detected light with the analyser (38) and
(e) displaying the results of the analysis with said display (30).

13. A method of determining tristimulus values of the sample (14) from the data produced by the analysis of claim 12 and further comprising:

a) determining the reflectance response of the sample (14) with a plurality of detector elements (21) of the detector (17,18,39);
(b) multiplying the sample reflectance response of each detector element (21) by a corresponding weighting determined from low resolution spectral data for each tristimulus function curve and
(c) summing the products thus obtained in step b) to produce the tristimulus values for the color of the color sample (14).

14. A method according to claim 13, wherein the weighting coefficients for each tristimulus function curve x, y and z are obtained by:

(i) correcting the tristimulus function curve representing sensitivity data of the human eye by multiplying it with the spectral power distribution curve of the illuminant;
(ii) determining the spectral response curve of the detector elements (21) represented as a series of generally triangular pass bands; and
(iii) fitting the illuminant corrected tristimulus function curves with a multiple linear combination of the generally triangular pass bands representing the spectral response curve. J

15. The method of claims 13 or 14, further comprising a step of calculating gain coefficients to adjust numerically the response of each detector element (21) to be equal to the reflectance of a white calibration tile at an appropriate wavelength.

16. The method of any one of claims 13 to 15 and further comprising:

multiplying the sample reflectance response of each detector element (21) first by a corresponding gain coefficient and then by a corresponding weighting coefficient; and
adding the data obtained above for all detector elements (21) and scaling to correct for the tristimulus values (Xo, Yo, Zo) for perfect white color for the specific illumination conditions employed.

17. The method of any one of claims 13 to 16 and wherein the sample reflectance response is determined by ten to sixteen detector elements (21).

18. The method of any one of claims 12 to 17 wherein the three light sources (11a, 11b, 11c) are used to illuminate the sample (14) from three corresponding illumination angles having values of about -30°, 0° and 65°, as measured from the sample normal.

19. The method of any one of claims 12 to 18 and wherein said detection angle has a value of about 35° to 55° and preferably about 45° as measured from the sample normal.

Patentansprüche

1. Kolorimeter (10), umfassend eine Bestrahlungseinrichtung (12), die eine Mehrzahl von Lichtquellen (11a, 11b, 11c) umfaßt, um nacheinander eine Farbfilmprobe (14) unter einer Vielzahl von entsprechenden Beleuchtungswinkeln zu beleuchten, einen Lichtempfänger (17, 18, 39), der das von der Probe (14) reflektierte Licht (16) in einem Erkennungswinkel erkennen kann, der von jedem der Beleuchtungswinkel abweicht, ein Analysegerät (38) zum Analysieren des erkannten Lichts, eine Anzeigevorrichtung (30) zum Anzeigen der Ergebnisse einer Analyse sowie eine Steuerungseinrichtung (29) zum Steuern der Bestrahlungseinrichtung (12), des Lichtempfängers (17, 18, 39), des Analysegeräts (38) und der Anzeigevorrichtung (30); dadurch gekennzeichnet, daß nur drei Lichtquellen (11a, 11b, 11c) vorhanden sind, die auf einer gemeinsamen Ebene senkrecht zu der Oberfläche der Probe (14) angeordnet sind und auf einem Kreisbogen liegen, dessen Mittelpunkt sich beim Einsatz auf der Oberfläche der Probe (14) befindet, wobei die Lichtquellen (11a, 11b, 11c) des weiteren so angeordnet sind, daß sie die Probe unter drei entsprechenden Beleuchtungswinkeln mit Werten von etwa -35° bis -20°, -10° bis +10° und 20° bis 75° beleuchten, gemessen von der Senkrechten zu der Probe aus, eine aktive Rückkopplungsschaltung (22, 25) vorhanden ist, um im Betrieb eine festgelegte Farbtemperatur für die Lichtquellen (11a, 11b, 11c) aufrechtzuerhalten, der Lichtempfänger (17, 18, 39) so angeordnet ist, daß er reflektiertes Licht in der gleichen Ebene wie die Lichtquellen (11a, 11b, 11c) empfängt, und die Lichtquellen (11a, 11b, 11c), derLichtempfänger (17, 18, 39), die Steuerungseinrichtung (29), das Analysegerät (38), die aktive Rückkopplungsschaltung (22, 25) und die Anzeigevorrichtung (30) alle in einem einzigen Gehäuse untergebracht sind, wodurch das Kolorimeter in seiner Gesamtheit tragbar ist und an verschiedenen Plätzen zur Analyse der Probe (14) an Ort und Stelle eingesetzt werden kann.

2. Kolorimeter (10) nach Anspruch 1, worin die drei Lichtquellen (11a, 11b, llc) so angeordnet sind, daß sie die Probe unter drei entsprechenden Beleuchtungswinkeln mit Werten von etwa -30°, 0° und 65° beleuchten, gemessen von der Senkrechten zu der Probe aus.

3. Kolorimeter (10) nach Anspruch 1 oder 2, worin der Erkennungswinkel einen Wert von etwa 35° bis 55° und vorzugsweise von etwa 45° aufweist, gemessen von der Senkrechten zu der Probe aus.

4. Kolorimeter (10) nach einem der Ansprüche 1 bis 3, worin der Lichtempfänger (17, 18, 39) eine achromatische Sammellinse (13), die in einem Abstand von etwa dem Zweifachen ihrer Brennweite von der Probe angeordnet ist, und einen Monochromator (19) aufweist, der ein Beugungsgitter (17) und eine Anordnung von Detektordioden (18) umfaßt, und wobei der Monochromator (19) entgegengesetzt der Probenseite der Linse (13) angebracht ist.

5. Kolorimeter (10) nach Anspruch 4, worin ein Eintrittsschlitz (15) in den Monochromator (19) in einem Abstand von etwa einer Brennweite von der Linse (13) angeordnet ist.

6. Kolorimeter (10) nachAnspruch 4 oder 5, worin die Anordnung von Detektordioden (18) zehn bis sechzehn Detektorelemente (21) aufweist.

7. Kolorimeter (10) nach einem der Ansprüche 1 bis 6, worin die Bestrahlungseinrichtung (12) auch drei Linsen (12a, 12b, 12c) umfaßt, die den drei Lichtquellen (11a, 11b, 11c) entsprechen, wobei jede der Linsen (12a, 12b, 12c) in einem Abstand von etwa einer Brennweite von einem Glühfaden einer entsprechenden Lichtquelle (11a, 11b, 11c)

angeordnet ist.

8. Kolorimeter (10) nach einem der Ansprüche 1 bis 7 und des weiteren umfassend:

eine Zwischenflächenplatte (33), die über der Bestrahlungseinrichtung (12) und dem Lichtempfänger (39, 18) angebracht ist,
wobei die Zwischenflächenplatte (33) eine mittige Öffnung aufweist, so daß das Licht durch diese hindurchtreten kann; und
eine Einrichtung, um das Kolorimeter (10) lösbar an der Probe (14) zu befestigen.

9. Kolorimeter nach Anspruch 8, worin:
die Befestigungseinrichtung eine Mehrzahl von Magnetfüßen (34) aufweist, die um die mittige Öffnung herum angeordnet sind und durch die Zwischenflächenplatte (33) hindurchragen.

10. Kolorimeter nach Anspruch 9 und des weiteren umfassend:

einen allgemein ringförmigen flexiblen Magneten (36), der konzentrisch zu der mittigen Öffnung positioniert ist, um eine lichtundurchlässige Abdichtung um diese herum zu schaffen; und
eine elastische Folie (35), die zwischen der Zwischenflächenplatte und dem flexiblen Magneten (36) angeordnet ist, um die Probenoberfläche (14) zu schützen.

11. Kolorimeter nach Anspruch 8, 9 oder 10, worin
die Bestrahlungseinrichtung (12) und der Lichtempfänger (39, 18) in einem Halbkreis um die mittige Öffnung herum positioniert sind.

12. Verfahren zum Analysieren der Farbe einer Farbfilmprobe (14), umfassend die folgenden Schritte:

(a) Aufstellen eines tragbaren Kolorimeters (10) an einem Platz im Bereich der Farbfilmprobe (14), wobei das Kolorimeter eine Bestrahlungseinrichtung umfaßt, die nur aus drei Lichtquellen (lla, 11b, llc) besteht, die auf einer gemeinsamen Ebene senkrecht zu der Oberfläche der Probe (14) angeordnet sind und auf einem Kreisbogen liegen, dessen Mittelpunkt sich auf der Oberfläche der Probe (14) befindet, eine aktive Rückkopplungsschaltung (22, 25), um eine festgelegte Farbtemperatur für die Lichtquellen aufrechtzuerhalten, einen Lichtempfänger (17, 18, 39), der reflektiertes Licht in der gleichen Ebene empfängt wie die Lichtquellen (11a, 11b, 11c), ein Analysegerät (38) zum Analysieren des erkannten Lichts, eine Anzeigevorrichtung (30) zum Anzeigen der Ergebnisse der Analyse, sowie eine Steuerungseinrichtung (29);
wobei die Lichtquellen (11a, 11b, 11c), der Lichtempfänger (17, 18, 39), das Analysegerät (38), die aktive Rückkopplungsschaltung (22, 25), die Anzeigevorrichtung (30) und die Steuerungseinrichtung (29) alle in einem einzigen Gehäuse untergebracht sind;
(b) Einsetzen der Steuerungseinrichtung (29) zum Steuern des Lichtempfängers (17, 18, 39), des Analysegeräts (38) und der Anzeigevorrichtung (30), sowie des Betriebs der Bestrahlungseinrichtung und der Rückkopplungsschaltung (22, 25), so daß die Lichtquellen (11a, 11b, 11c) die Farbfilmprobe (14) nacheinander unter einer Vielzahl von Beleuchtungswinkeln beleuchten, die den Lichtquellen (11a, 11b, 11c) entsprechen, und die etwa -35° bis -20° bzw. -10° bis +10° bzw. 20° bis 75° betragen, gemessen von der Senkrechten zu der Probe aus;
(c) aufeinanderfolgendes Erkennen des durch die Probe (14) von jeder der Lichtquellen (11a, 11b, 11c) reflektierten Lichts (16) mit dem Lichtempfänger (17, 18, 39), der auf einen Erkennungswinkel eingestellt ist, der von jedem der Beleuchtungswinkel abweicht;
(d) Analysieren des erkannten Lichts mit dem Analysegerät (38) und
(e) Anzeigen der Ergebnisse der Analyse an der Anzeigevorrichtung (30).

13. Verfahren zum Bestimmen der Tristimuluswerte der Probe (14) aus den durch die Analyse gemäß Anspruch 12 gewonnenen Werten, und des weiteren umfassend:

(a) Bestimmen des Reflexionsvermögens der Probe (14) mit einer Mehrzahl von Detektorelementen (21) des Lichtempfängers (17, 18, 39);
(b) Multiplizieren des Reflexionsvermögens jedes Detektorelementes (21) mit einer entsprechenden Gewichtung, die aus den eine geringe Auflösung zeigenden Spektralwerten für jede Tristimulus-Funktionskurve bestimmt wurde, und

(c) Summieren der auf diese Weise in Schritt (b) erzielten Produkte, um die Tristimuluswerte für die Farbe der Farbprobe (14) zu gewinnen.

14. Verfahren nach Anspruch 13, worin die Gewichtungsfaktoren für jede Tristimulus-Funktionskurve x, y und z gewonnen werden durch:

(i) Korrigieren der Tristimulus-Funktionskurve, die Empfindlichkeitswerte des menschlichen Auges darstellt, durch Multiplizieren derselben mit der Kurve der spektralen Energieverteilung der Lichtquelle;
(ii) Bestimmen der Kurve der Farbenempfindlichkeit der Detektorelemente (21), dargestellt als eine Reihe von im allgemeinen dreieckigen Durchlaßbereichen; und
(iii) Zusammenpassen der mit der Lichtquelle korrigierten Tristimulus-Funktionskurven mit einer mehrfachen linearen Kombination der im allgemeinen dreieckigen Durchlaßbereiche, die die Farbenempfindlichkeitskurve darstellen.

15. Verfahren nach Anspruch 13 oder 14, des weiteren umfassend einen Schritt des Berechnens von Verstärkungsfaktoren, um numerisch das Ansprechen jedes Detektorelementes (21) so einzustellen, daß dieses gleich dem Reflexionsvermögens einer weißen Kalibrierungsfliese bei einer geeigneten Wellenlänge ist.

16. Verfahren nach einem der Ansprüche 13 bis 15, und des weiteren umfassend:

Multiplizieren des Reflexionsvermögens der Probe für jedes Detektorelement (21) zuerst mit einem entsprechenden Verstärkungsfaktor und dann mit einem entsprechenden Gewichtungsfaktor; und
Addieren der oben für alle Detektorelemente (21) gewonnenen Werte und Skalieren derselben zwecks Korrektur der Tristimuluswerte (X_0, Y_0, Z_0) für vollkommen weiße Farbe für die angewandten spezifischen Beleuchtungsbedingungen.

17. Verfahren nach einem der Ansprüche 13 bis 16, worin das Reflexionsvermögen der Probe mit zehn bis sechzehn Detektorelementen (21) bestimmt wird.

18. Verfahren nach einem der Ansprüche 12 bis 17, worin die drei Lichtquellen (11a, 11b, 11c) dazu dienen, die Probe (14) unter drei entsprechenden Beleuchtungswinkeln mit Werten von etwa -30°, 0° und 65° zu beleuchten, gemessen von der Senkrechten zu der Probe aus.

19. Verfahren nach einem der Ansprüche 12 bis 18, worin der Erkennungswinkel einen Wert von etwa 35° bis 55° und vorzugsweise von etwa 45° aufweist, gemessen von der Senkrechten zu der Probe aus.

Revendications

1. Un colorimètre (10) comprenant un moyen d'irradiation (12) qui comprend une multiplicité de sources lumineuses (11a, llb, llc) destinés à éclairer successivement un échantillon de film coloré (14) sous une multiplicité d'angles d'éclairage correspondants, un détecteur (17, 18, 39) propre à détecter la lumière réfléchie (16) par l'échantillon (14) sous un angle de détection différent de tous lesdits angles d'éclairage, un analyseur (38) destiné à analyser la lumière détectée, un organe d'affichage (30) propre à afficher les résultats d'une analyse et un moyen contrôleur (29) propre à piloter le moyen d'irradiation (12), le détecteur (17, 18, 39), l'analyseur (38) et l'organe d'affichage (30) ; caractérisé en ce qu'il y a trois sources lumineuses (11a, 11b, 11c) seulement, disposées sur un plan commun normal à la surface de l'échantillon (14) et se trouvant sur un arc dont le centre est sur la surface de l'échantillon (14) en utilisation, les sources lumineuses (11a, 11b, 11c) étant en outre disposées de façon à éclairer l'échantillon sous trois angles d'éclairage correspondants ayant des valeurs d'environ -35 à -20°, -10 à +10° et +20 à +75°, mesurées par rapport à la normale à l'échantillon, en ce qu'un circuit de rétroaction actif (22, 25) est disposé à l'effet de maintenir en fonctionnement une température de couleur fixe pour les sources lumineuses (11a, 11b, 11c), en ce que le détecteur (17, 18, 39) est disposé de manière à recevoir de la lumière réfléchie dans le même plan que les sources lumineuses (11a, 11b, 11c), et en ce que les sources lumineuses (11a, 11b, 11c), le détecteur (17, 18, 39), le moyen contrôleur (29), l'analyseur (38), le circuit de rétroaction actif (22, 25) et l'organe d'affichage (30) sont tous intégrés dans un même boîtier, en rendant ainsi le colorimètre portable dans son ensemble et en permettant de l'utiliser en différents emplacements pour analyser l'échantillon (14) in situ.

2. Le colorimètre (10) de la revendication 1, dans lequel les trois sources lumineuses (11a, 11b, 11c) sont disposées

de manière à éclairer l'échantillon sous trois angles d'éclairage correspondants ayant des valeurs d'environ -30°, 0° et 65°, mesurés par rapport à la normale à l'échantillon.

3. Le colorimètre (10) de la revendication 1 ou 2, dans lequel ledit angle de détection, mesuré par rapport à la normale à l'échantillon, a une valeur d'environ 35 à 55°, et de préférence d'environ 45°.

4. Le colorimètre (10) de l'une quelconque des revendications 1 à 3, dans lequel ledit détecteur (17, 18, 39) comporte une lentille collectrice achromatique (13) montée à une distance de l'échantillon égale environ au double de sa distance focale, et un monochromateur (19) comprenant un réseau de diffraction (17) et un ensemble de détecteurs à diodes (18), ledit monochromateur (19) étant monté du côté de ladite lentille (13) opposé à celui de l'échantillon.

5. Le colorimètre (10) de la revendication 4, dans lequel une fente d'entrée (15) dudit monochromateur (19) est montée à une distance de ladite lentille (13) d'environ une distance focale.

6. Le colorimètre de la revendication 4 ou 5, dans lequel ledit ensemble de détecteurs à diodes (18) comprend dix à seize éléments de détection (21).

7. Le colorimètre (10) de l'une quelconque des revendications 1 à 6, dans lequel ledit moyen d'irradiation (12) comprend aussi trois lentilles (12a, 12b, 12c) correspondant auxdites trois sources lumineuses (11a, 11b, 11c), chacune desdites lentilles (12a, 12b, 12c) étant montée à une distance d'environ une distance focale d'un filament de source lumineuse (11a, 11b, 11c) correspondante.

8. Le colorimètre (10) de l'une quelconque des revendications 1 à 7, comprenant en outre :

une plaque d'interface (33) montée par-dessus ledit moyen d'irradiation (12) et ledit détecteur (39, 18), ladite plaque d'interface (33) comportant un orifice central pour permettre à la lumière de la traverser ; et
un moyen permettant de fixer amoviblement le colorimètre (10) sur l'échantillon (14).

9. Le colorimètre de la revendications 8, dans lequel ledit moyen de fixation comprend une multiplicité de pieds magnétiques (34) placés autour dudit orifice central et dépassant à travers ladit plaque d'interface (33).

10. Le colorimètre de la revendication 9, comprenant en outre un aimant flexible de forme globalement toroïdale (36) disposé concentriquement par rapport audit orifice central pour réaliser une jonction étanche à la lumière autour dudit orifice, et une feuille élastique (35) disposée entre ladite plaque d'interface et ledit aimant flexible (36) à l'effet de protéger la surface de l'échantillon (14).

11. Le colorimètre de la revendication 8, 9 ou 10, dans lequel ledit moyen d'irradiation (12) et ledit détecteur (39, 18) sont disposés dans un demi-cercle autour dudit orifice central.

12. Un procédé pour analyser la couleur d'un échantillon de film coloré (14) comprenant les opérations consistant :

(a) à installer un colorimètre portable (10) en un endroit de l'environnement de l'échantillon de film coloré (14), le colorimètre comprenant un moyen d'irradiation comprenant trois sources lumineuses (11a, 11b, 11c) seulement, qui sont disposées sur un plan commun normal à la surface de l'échantillon (14) et se trouvent sur un arc dont le centre est sur la surface de l'échantillon (14), un circuit de rétroaction actif (22, 25) propre à maintenir une température de couleur fixe pour les sources lumineuses, un détecteur (17, 18, 39) propre à recevoir de la lumière réfléchie dans le même plan que les sources lumineuses (11a, 11b, 11c), un analyseur (38) propre à analyser la lumière détectée, un organe d'affichage (30) propre à afficher les résultats de l'analyse et un moyen contrôleur (29) ; les sources lumineuses (11a, 11b, 11c), le détecteur (17, 18, 39), l'analyseur (38), le circuit de rétroaction actif (22, 25), l'organe d'affichage (30) et le moyen contrôleur (29) étant tous intégrés dans un même boîtier ;
(b) à utiliser le moyen contrôleur (29) pour piloter le détecteur (17, 18, 39), l'analyseur (38), l'organe d'affichage (30) ainsi que le fonctionnement du moyen d'irradiation et du circuit de rétroaction (22, 25) pour faire éclairer successivement l'échantillon de film coloré (14) par les sources lumineuses (11a, 11b, 11c) sous plusieurs angles d'éclairage correspondant auxdites sources lumineuses (11a, 11b, 11c) qui sont respectivement d'environ -35 à -20°, -10 à +10° et +20 à +75°, mesurés par rapport à la normale à l'échantillon ;
(c) à détecter successivement la lumière (16) en provenance de chacune desdites sources lumineuses (11a, 11b, 11c) qui est réfléchie par l'échantillon (14) avec le détecteur (17, 18, 39) qui est réglé à un angle de

détection différent de chacun desdits angles d'éclairage ;
(d) à analyser la lumière détectée avec l'analyseur (38) ; et
(e) à afficher les résultats de l'analyse avec ledit organe d'affichage (30).

13. Un procédé pour déterminer les valeurs "tristimulus" de l'échantillon (14) à partir des données fournies par l'analyse de la revendication 12, comprenant en outre les opérations consistant :

(a) à déterminer la réponse de réflectance de l'échantillon (14) avec une multiplicité d'éléments de détection (21) du détecteur (17, 18, 39) ;
(b) à multiplier la réponse de réflectance d'échantillon de chacune élément de détection (21) par un facteur de pondération correspondant déterminé à partir de données spectrales à basse résolution pour chaque courbe de fonction trichromatique et
(c) à sommer les produits ainsi obtenus à l'opération (b) pour obtenir les valeurs "tristimulus" pour la couleur de l'échantillon coloré (14).

14. Un procédé selon la revendication 13, dans lequel les coefficients de pondération pour chaque courbe de fonction tristumulus x, y et z sont obtenus :

(i) en corrigeant la courbe de fonction tristimulus représentant des données de sensibilité de l'oeil humain par multiplication de celle-ci avec la courbe de distribution de puissance spectrale de l'illuminant ;
(ii) en déterminant la courbe de réponse spectrale des éléments de détection (21) représentée sous forme de série de fonctions passe-bande globalement triangulaires ; et
(iii) en approchant les courbes de fonction tristimulus à correction d'illuminant par une combinaison linéaire multiple des fonctions passe-bande globalement triangulaires représentant la courbe de réponse spectrale.

15. Le procédé de l'une quelconque des revendications 13 ou 14, comprenant en outre l'étape suivant laquelle on calcule des coefficients de gain pour régler numériquement la réponse de chaque élément de détection (21) pour être égale à la réflectance d'une tuile d'étalonnage blanche, à une longueur d'onde appropriée.

16. Le procédé de l'une quelconque des revendications 13 à 15 comprenant en outre les opérations consistant à multiplier la réponse de réflectance d'échantillon de chaque élément de détection (21) d'abord par un coefficient de gain correspondant puis par un coefficient de pondération correspondant, et à additionner les données obtenues ci-dessus pour tous les éléments de détection (21) et à coefficienter pour corriger les valeurs tristimulus (Xo, Yo, Zo) pour une couleur d'un blanc parfait pour les conditions d'éclairage particulières utilisées.

17. Le procédé de l'une quelconque des revendications 13 à 16 et dans lequel la réponse de réflectance d'échantillon est déterminée par dix à seize éléments de détection (21).

18. Le procédé de l'une quelconque des revendications 12 à 17 dans lequel les trois sources lumineuses (IIa, IIb, IIc) sont utilisées pour éclairer l'échantillon (14) sous trois angles d'éclairage correspondants ayant des valeurs d'environ -30°, 0° et +65°, mesurés par rapport à la normale à l'échantillon.

19. Le procédé de l'une quelconque des revendications 12 à 18 dans lequel ledit angle de détection, mesuré par rapport à la normale à l'échantillon, a une valeur d'environ 35 à 55°, et de préférence d'environ 45°.

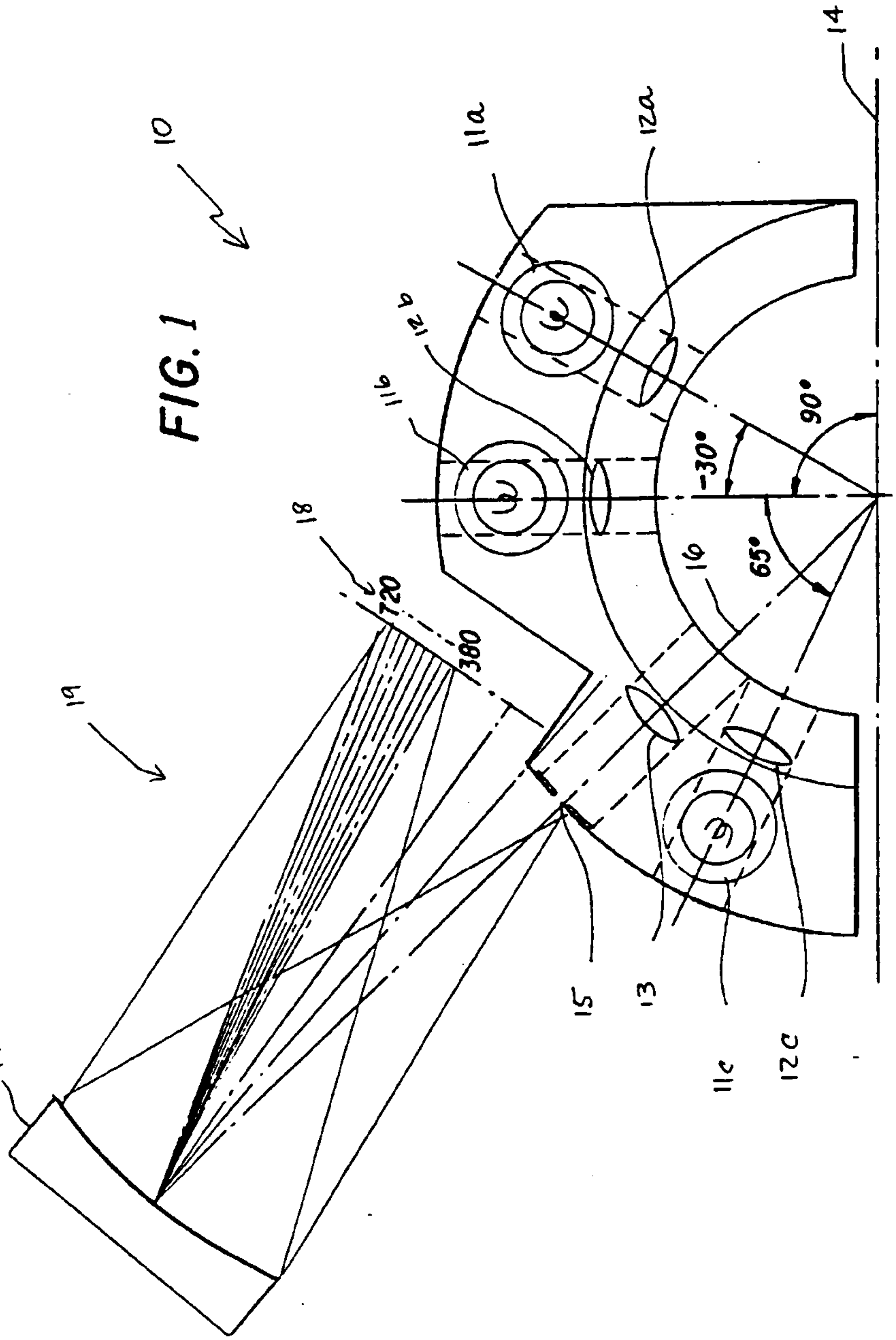


FIG. 1

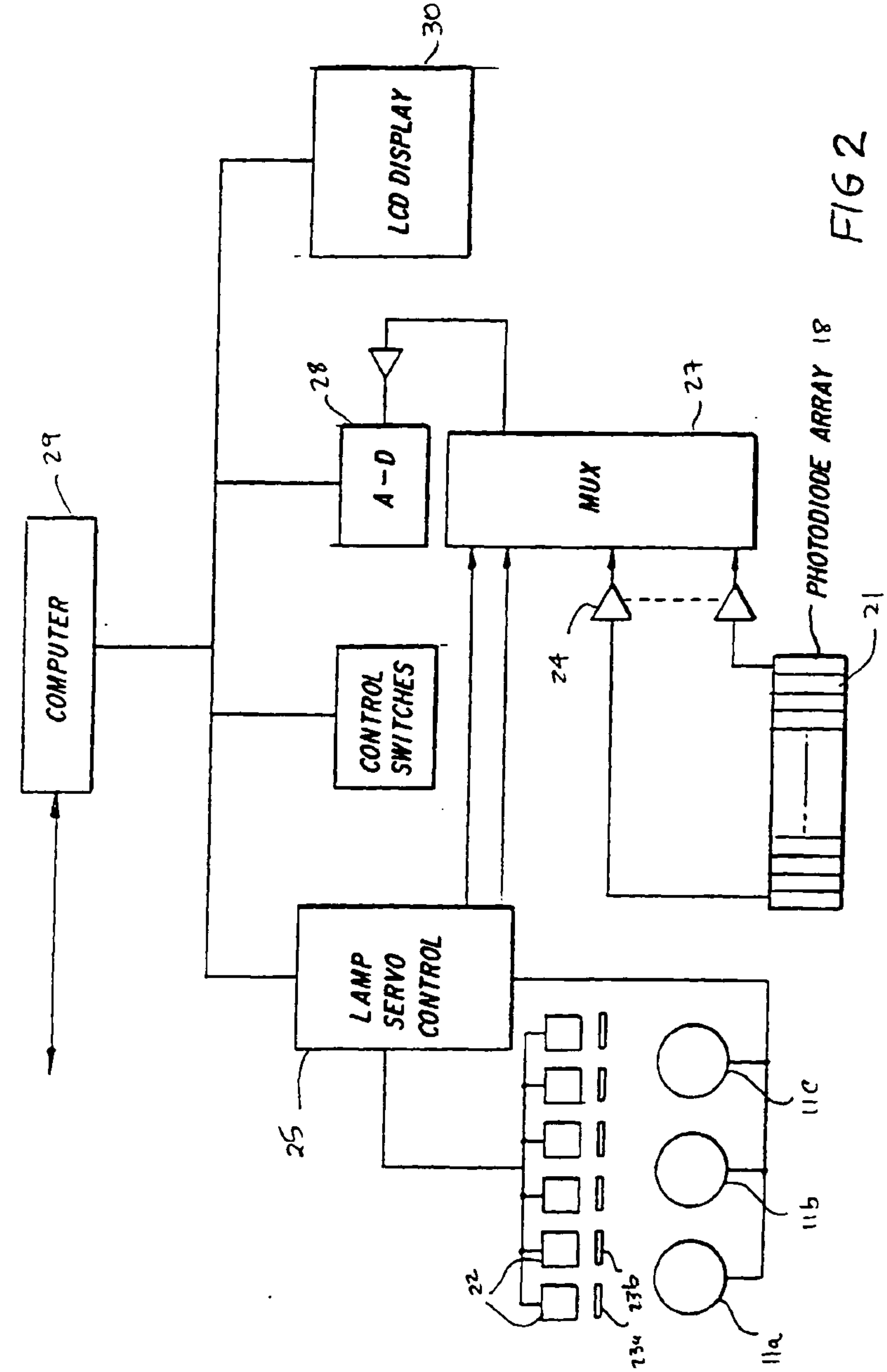

COMPUTER
29
CONTROL SWITCHES
LAMP SERVO CONTROL
25
A-D
28
MUX
27
LCD DISPLAY
30
PHOTODIODE ARRAY 18
21
24
22
23a
23b
11a
11b
11c

FIG 2

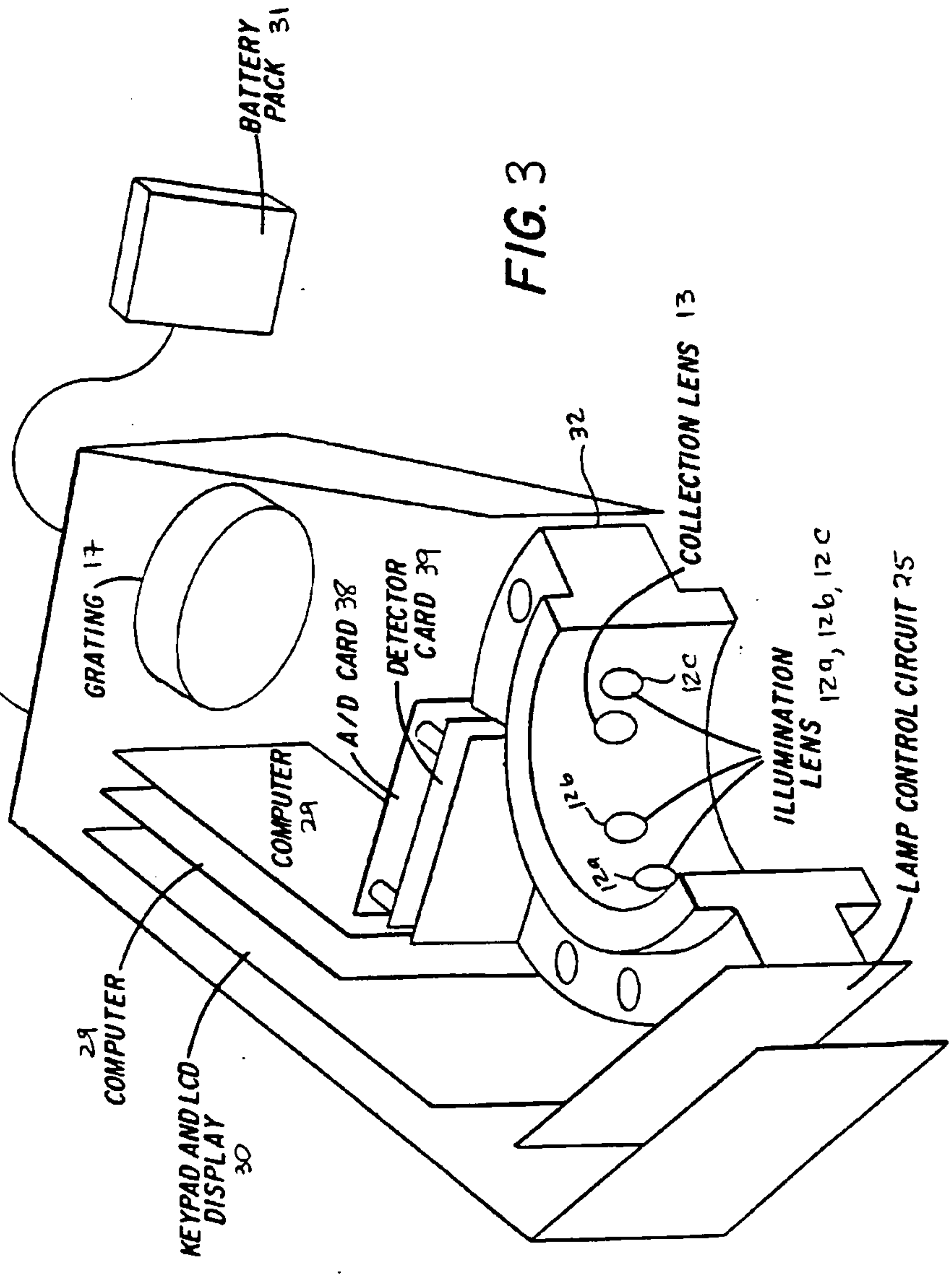

BATTERY PACK 31
10
GRATING 17
A/D CARD 38
DETECTOR CARD 39
COMPUTER 29
32
COLLECTION LENS 13
12c
12b
12a
ILLUMINATION LENS 12a, 12b, 12c
LAMP CONTROL CIRCUIT 25
29 COMPUTER
KEYPAD AND LCD DISPLAY 30

FIG. 3

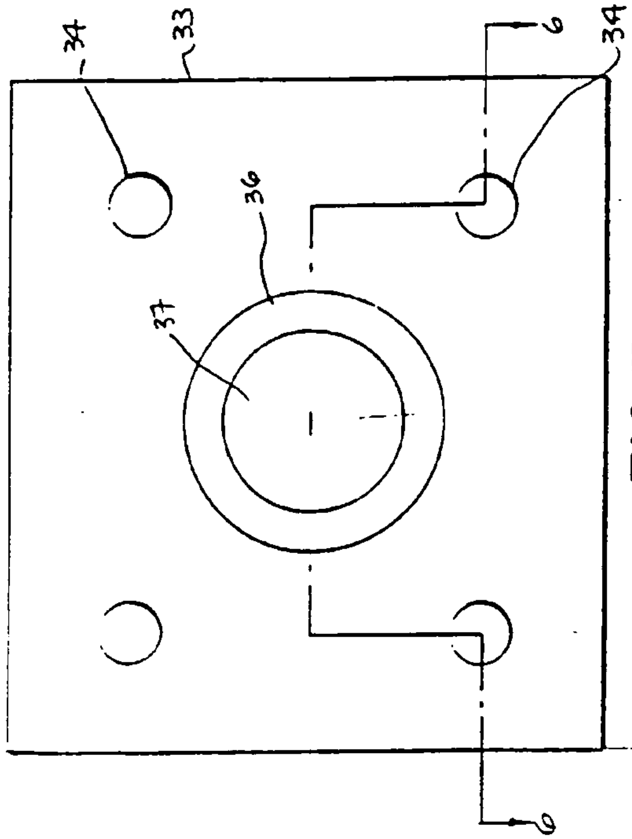


FIG. 5

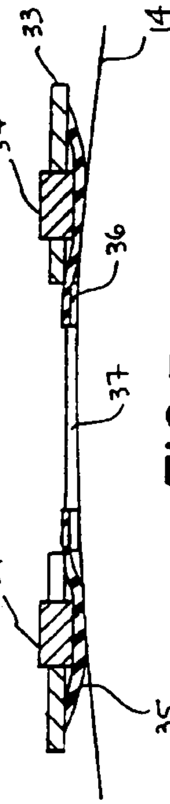
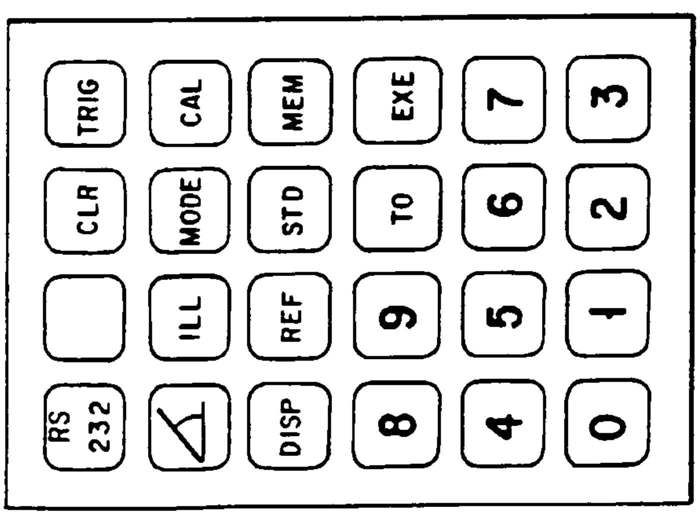


FIG. 7

FIG. 4



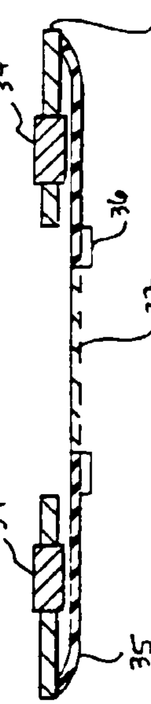


FIG. 6

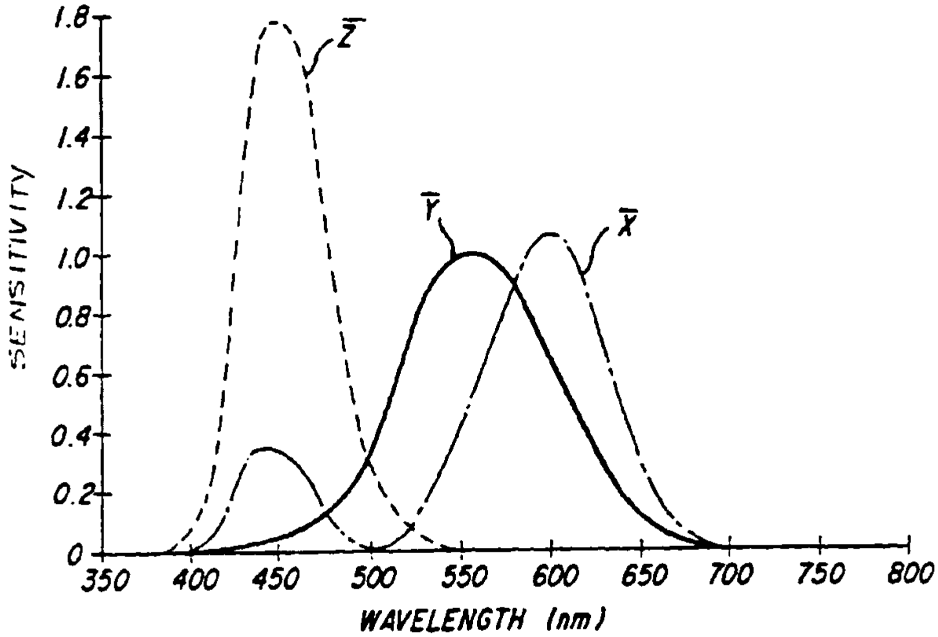

1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
SENSITIVITY
$\bar{Z}$
$\bar{Y}$
$\bar{X}$
350
400
450
500
550
600
650
700
750
800
WAVELENGTH (nm)

FIG. 8

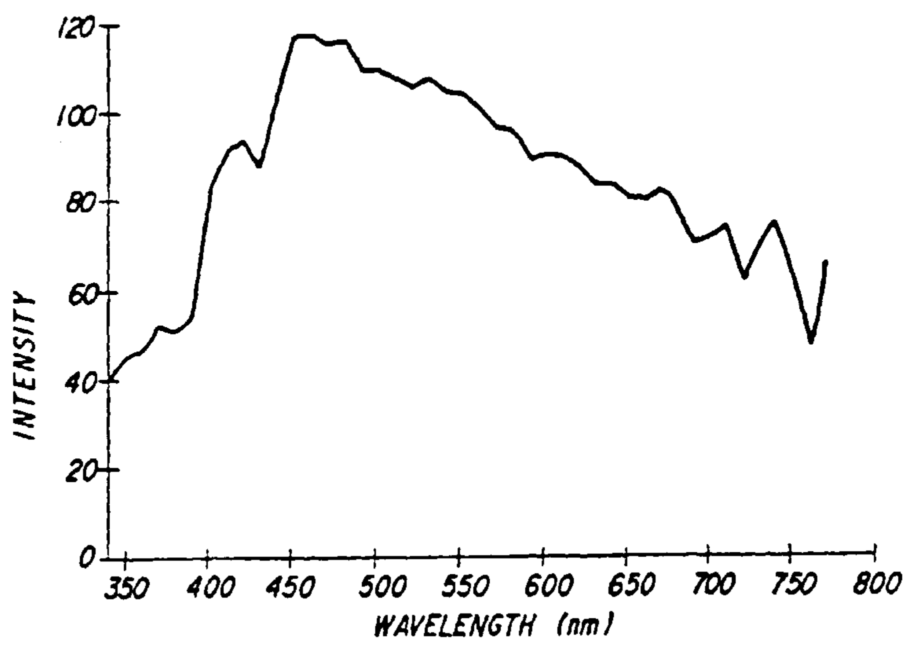

120
100
80
60
40
20
0
INTENSITY
350
400
450
500
550
600
650
700
750
800
WAVELENGTH (nm)

FIG. 9

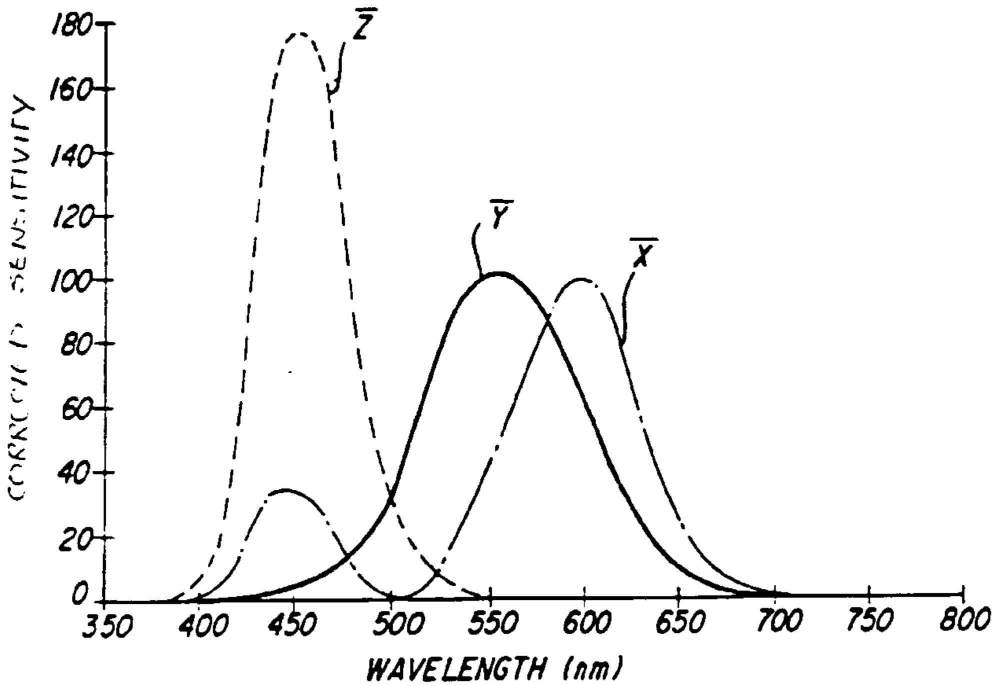

180
160
140
120
100
80
60
40
20
0
350
400
450
500
550
600
650
700
750
800
WAVELENGTH (nm)
$\bar{Z}$
$\bar{Y}$
$\bar{X}$

FIG. 10

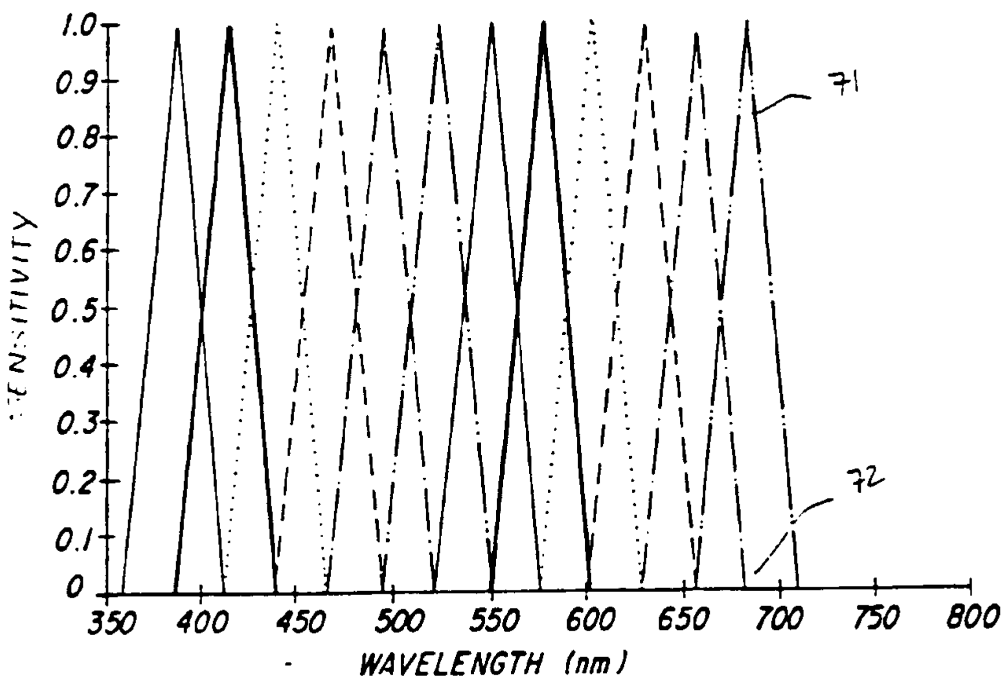

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
350
400
450
500
550
600
650
700
750
800
WAVELENGTH (nm)
71
72

FIG. 11

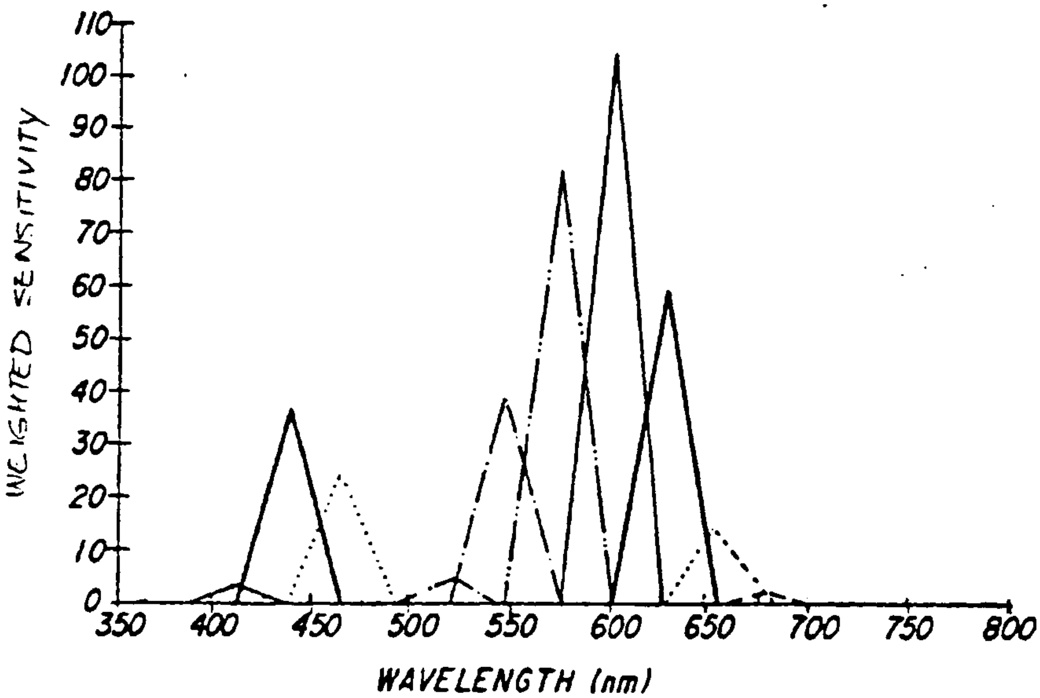

110
100
90
80
70
60
50
40
30
20
10
0
WEIGHTED SENSITIVITY
350
400
450
500
550
600
650
700
750
800
WAVELENGTH (nm)

FIG. 12

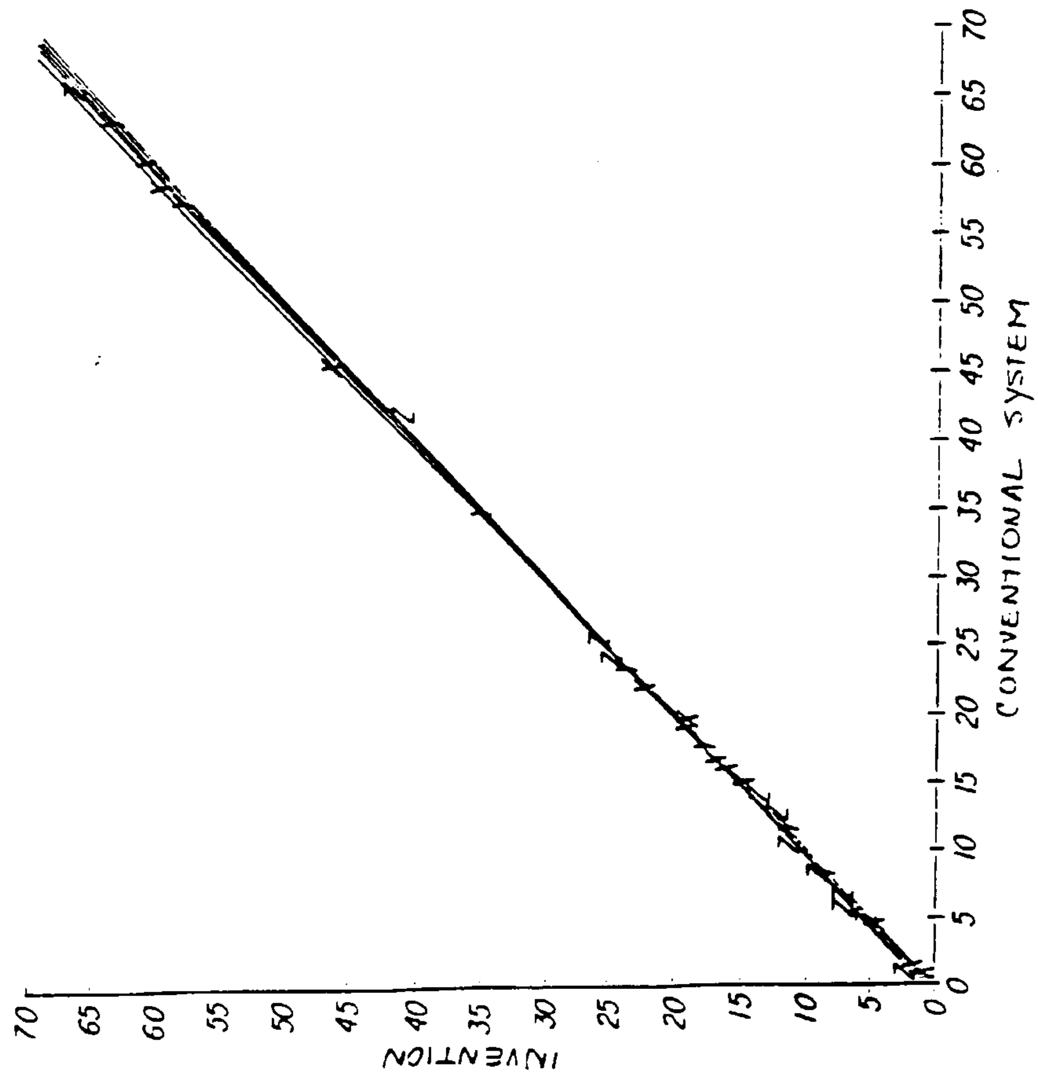

INVENTION
CONVENTIONAL SYSTEM
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

FIG. 13